AMENDMENTS TO THE SPECIFICATION

Please replace Paragraphs [0001], [0002], [0006], [0007], [0013] - [0016], [0023] - [0038], [0040] and [0041] with the following paragraph rewritten in amendment format:

BACKGROUND ~~OF THE DISCLOSURE~~

[0001] This ~~invention~~disclosure was developed in the course of work under U.S. government contract MDA972-99-9-0003. The U.S. government may possess certain rights in the ~~invention~~disclosure.

[0002] The present ~~invention~~disclosure is directed to an improved control system and method and in particular, to a system and method for command signal conditioning in high response systems.

[0006] The present ~~invention~~disclosure overcomes the foregoing limitations. In accordance with the present ~~invention~~disclosure, the need for a cost-effective control system and method which reduces waste energy and heat generation and minimally affects the size, weight and response of the system is fulfilled.

Summary ~~of the Invention~~

[0007] A control system having a central digital controller having a digital controller frame rate and a command signal, a motor, and a motor controller in communication with the central digital controller and the motor, the motor controller having a motor controller frame rate higher than the digital controller frame rate is disclosed. The control system comprises a signal conditioner adapted to condition the command signal so as to generate a modified command signal at the motor controller

frame rate. The signal conditioner comprises a computer readable medium having computer readable program code embodied thereon.

[0013] Further features and advantages of the present ~~invention~~disclosure, as well as the structure and operation of various embodiments of the present ~~invention~~disclosure, are described in detail below with reference to the accompanying drawings.

[0014] Figure 1 is a block diagram of a portion of a motion control system in accordance with the present ~~invention~~disclosure;

[0015] Figure 2 is a block diagram of a method of command signal conditioning in accordance with one embodiment of the present ~~invention~~disclosure;

[0016] Figure 3 is a block diagram of a method of command signal conditioning in accordance with another embodiment of the present ~~invention~~disclosure;

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0023] The present ~~invention~~disclosure is directed to an improved control system and method. While the system 10 will be described with respect to a motion control system, it can be appreciated that it can be applied to any high response system. The system 10, a portion of which is shown in Figure 1, typically comprises a central digital controller 12 which controls one or more actuator systems 14. Each actuator system 14 includes among other things an electric motor 16 and a digital motor controller 18 for control thereof. The central controller 12 generates an input or command signal which is

transmitted to the appropriate motor controller 18 and conditioned in accordance with the present ~~invention~~disclosure.

[0024] Conditioning of the command signal is accomplished by using the lower rate data from the central controller 12 to produce a modified command signal at the frame rate of the motor controller 18. In one embodiment ~~of the present invention~~ as shown in Figure 2, conditioning of the command signal involves interpolation of the command signal over a plurality of frames and in particular, calculating a moving average at the frame rate of the motor controller 18 and adjusting the command signal of the central controller 12 accordingly. This approach will be hereinafter referred to as the moving average approach. While this approach is preferably implemented in software residing on the motor controller 18, it can be appreciated that it can be implemented in software residing on other devices of the control system or in hardware. The moving average is calculated as follows:

$$(C_M + C_{M-1} + C_{M-2} + \ldots + C_{M+1-N})/N$$

[0025] wherein C_M = the value of the command signal from the central controller as 12 as sampled by the motor controller 18 at a current point in time;

[0026] C_{M-1} = the value of the command signal from the central controller 12 as sampled by the motor controller 18 one motor controller frame in the past (and so on for C_{M-2}, etc.); and

[0027] N = an integer ratio of the motor control frame rate divided by the central controller 12 frame rate.

[0028] The quantity of the frames used for the moving average is equal to the integer value of the frame rate of the motor controller 18 divided by the frame rate of the

central controller 12. Therefore, the frame rate of the motor controller 18 must be very close to an integer multiple of the frame rate of the central controller 12.

[0029] The moving average approach conditions the stair step command signal 20 of the central controller 12 as illustrated in Figure 4. In this example, the frame rate of the central controller 12 was 100 frames per second, and the frame rate of the motor controller 18 was 800 frames per second. Applying the moving average approach of Figure 2[[.]] to the command signal 20 resulted in the smooth waveform 22.

[0030] In another embodiment ~~of the present invention~~ as shown in Figure [[5]]3, conditioning of the command signal is accomplished through the use of a slewer-filter approach. This approach will be hereinafter referred to as the slewer-filter approach. In this embodiment, conditioning of the command signal is accomplished through extrapolation of the command signal over a plurality of frames using a first order hold 24 and first order filter 26 combination. As with the moving average approach, this approach is preferably implemented in software residing on the motor controller 18. However, it can be appreciated that it can be implemented in software residing on other devices of the control system 10 or in hardware. In one embodiment, a first order filter is used with a slewer ranging between 100 Hz to 800 Hz. The filter frequency is selected to attenuate the high frequency gain increase introduced by the first order hold. A 17 Hz filter fulfills this criteria in this embodiment. It can be appreciated, however, that other criteria for selecting the filter frequency or higher order filters may be used depending on the dynamic characteristics of the system and/or the computational throughput capabilities of the motor control electronics.

[0031] The first order hold is a linear extrapolation using the last two commands from the central controller 12 with the starting point of the linear extrapolation being the most recent command. It is calculated as follows:

$$\{C_c + T^* (C_c - C_{c-1}) / \Delta t_c\}$$

[0032] wherein T = the time from the most recent command from the central controller 12, updated at the motor controller 18 frame rate;

[0033] Δt_c = the time between frames of the central controller 12;

[0034] C_c = the most recent command from the central controller 12; and

[0035] C_{c-1} = the previous command from the central controller 12.

[0036] The slewer-filter approach adjusts the command signal as illustrated in Figure 5. Specifically, the command signal 28 from the central controller 12 is conditioned by the first order hold as shown by signal 30, resulting in the smoothed signal 32. The break point of the first order filter is preferably selected to negate the high frequency gain increase introduced by the extrapolation of the first order hold, thus maintaining near unity gain across the frequency range of the motion control system as illustrated in Figure 8b. A graph of the gain without the use of a filter is shown in Figure 8a. Unlike the moving average method, this method is applicable to motion control systems where the motor controller 18 frame rate is not an integer multiple of the central controller 12 frame rate. This flexibility, however, requires more complex software and improved numerical precision to implement.

[0037] As shown in Figs. 4 and 5, the signals 22 and 32 conditioned under the moving average approach and the slewer-filter approach, respectively, show only slight differences in amplitude, generally within thirty percent (30%) of the step change of the largest signal. The slewer-filter approach shows a slightly higher phase lag than the

moving average approach, but this phase lag is no more than the zero order hold response of the control system without the slewer-filter approach. Moreover, this phase lag can be tuned by adjusting the filter frequency to trade off gain and phase to best meet the dynamic response and stability requirements of the overall control system 10.

[0038] Figure 6 illustrates the reduction in heat generation resulting from use of the present ~~invention~~disclosure. Specifically, it compares the heat load generated by math models of a conceptual electromechanical actuator under a typical operation cycle. Graph 36 represents the heat load generated by the actuator without using either the moving average or slewer-filter approach. Graph 38 represents the heat load generated by the actuator using the moving average or slewer-filter approach. Figure 7 compares the corresponding comparative heat loads at the motor controller 18 for the same actuator of Figure 6.

[0040] By minimizing the need for additional cooling systems, this ~~invention~~disclosure reduces the weight of products in which it is incorporated. In an aircraft, weight savings typically result in significant operational and support cost savings. Most importantly, however, mathematical simulations have shown that the present ~~invention~~disclosure can significantly reduce waste energy and heat generation, in some cases by more than thirty percent (30%).

[0041] While the present ~~invention~~disclosure has been described by reference to specific embodiments and specific uses, it should be understood that other configurations and arrangements could be constructed, and different uses could be made, without departing from the scope of the ~~invention~~disclosure as set forth in the

following claims. In particular, the ~~invention~~disclosure can be used in any high response application.